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General Design Specifications for Heavy Duty Vehicle Analytical Instruments

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Appendix

General Design Specifications for Heavy Duty Vehicle Analytical Instruments.

1. Measurement accuracy:

A. All emission analyzers: Listed are suggested ranges for all emission analyzers. Select the appropriate ranges and number of ranges for each analyzer. The analyzers must operate between 20 percent and 95 percent of full-scale value for non-linear instruments (20 to 100 percent for linear analyzers) during the measurement of the emissions for each mode. The exceptions to the lower limit of this operating rule are:

(1) The analyzer response may be less than 20 percent of full-scale if the full-scale value is 120 ppm (or ppm C) or less.

(2) The analyzers response may be less than 20 percent of full-scale if the emissions from the engine are irratic and the integrated chart-deflection value is greater than 20 percent of full-scale.

(3) The analyzer response may be less than 20 percent of full-scale during the initial part of the CT mode provided that the integrated chart-deflection value is greater than 20 percent of full-scale.

The magnitude of full-scale value of the suggested ranges may vary somewhat to suit instrument characteristics or to facilitate data collection.

Suggested Ranges	Instrument Accuracy
0-10. ppm or ppm C	5 percent of full-scale
0-50. ppm or ppm C	2 percent of full-scale
0-100. ppm or ppm C	1 percent of full-scale
0-500. ppm or ppm C	1 percent of full-scale
0-1000. ppm or ppm C	1 percent of full-scale
0-5000. ppm or ppm C	1 percent of full-scale
0-10000. ppm or ppm C	1 percent of full-scale
0-50000. ppm or ppm C	1 percent of full-scale
0-10.00 percent	1 percent of full-scale
0-15.00 percent	1 percent of full-scale
0-20.00 percent	1 percent of full-scale

B. The dynamometer test stand and other instruments for measurement of power output shall be accurate to within ± 2 percent of full-scale at all power settings.

C. The fuel flow measurement instrumentation shall have a minimum accuracy of 1 percent of full-scale for each range used. Fuel flow measurements may not be used as official values if the readings are below 20 percent of full scale value unless the point accuracy has an error of less than 5 percent.

II. NDIR instruments: Nondisperative infrared (NDIR) analyzers shall be used for the continuous monitoring of carbon monoxide and carbon dioxide.

A. Analyzer description: The NDIR instruments operate on the principle of differential energy absorption from parallel beams of infrared energy. The energy is transmitted to a differential detector through parallel cells, one containing a reference gas, and the other, sample gas. The detector, charged with the component to be measured, transduces the optical signal to an electrical signal. The electrical signal thus generated is amplified and continuously recorded.

B. Analyzer specification:

Response time (pneumatic)--15 percent of full-scale in 0.5 seconds or less.

Response time (electrical)--95 percent of full-scale in 0.5 seconds or less.

Noise--±1 percent of full scale on most sensitive range.

Repeatability--±1 percent of full scale.

Zero drift--Less than ±1 percent of full-scale in 2 hours on all ranges.

Span drift--Less than ±1 percent of full-scale in 2 hours on all ranges.

Cell Temperature--Minimum 50°C maintained within ± 2°C.

C. Cell length: All NDIR instruments shall be equipped with cells of sufficient length to accurately measure the exhaust concentrations encountered during the test. (See I A.) Range changes shall be accomplished either by the use of stacked sample cells or changes in the electronic circuitry, or both.

D. Zero supression: Various techniques of zero supression may be used to increase readability. Note, that by supressing the zero response, the

readability of the emission response is increased, but accuracy of this response expressed as a percent of full-scale value does not change.

I/I. Total hydrocarbon analyser:

A. Analyser description: The measurement of total hydrocarbon is to be made by an analyser using a flame ionisation detector (FID). With this type detector an ionisation current proportional to the mass rate of hydrocarbon entering a hydrogen flame is measured by an electrometer amplifier and continuously recorded.

The analyser shall be fitted with a constant-temperature oven housing the detector and sample-handling components. It shall maintain temperature within ± 2°C of the set point.

The detector and sample-handling components shall be suitable for continuous operation at temperatures to 200°C.

B. Analyser specification:

Response time (pneumatic)--15 percent of full-scale in .5 seconds or less.

Response time (electrical)--95 percent of full scale in 0.5 seconds or less.

Noise--±1 percent of full scale on most sensitive range.

Repeatability--±1 percent of full scale.

Zero drift--Less than ±1 perecent of full scale in 2 hours on all ranges.

Span drift--Less than ±1 percent of full scale in 2 hours on all ranges.

Linearity--Response with propane in air shall be linear within ± 2 percent.

C. Detector response optimisation:

(1) Follow manufacture's instructions for instrument start-up and basic operating adjustments.

(a) The fuel shall contain 40 ± 1% hydrogen. The balance shall be helium. The mixture shall contain less than 2 ppm of hydrocarbon.

(b) The air shall contain 21 ± 1% oxygen. Compressed "hydrocarbon-free" grade of atmospheric air meets the oxygen-concentration requirements. The air shall contain less than 3 ppm C hydrocarbon.

(2) Set the oven temperature 5°C hotter than the required sampling-line temperature. Allow at least one-half hour after the oven has reached temperature for the system to equilibrate.

(3) Peak the detector: With the fuel and air set at the manufacturer's settings, introduce a mixture of propane in air to the detector. The propane concentration should be approximately 80 ppm C ± 20 ppm C. Determine the response at a given fuel flow from the difference between the span-gas response and the zero-gas response. Incrementally adjust the fuel flow above and below the manufacturer's specification. Record the span and zero response at these fuel flows. A plot of the difference between the span and zero response versus fuel flow will be similar to the one shown in Fig III-1. Adjust the fuel flow-rate to the rich side of the curve, as shown. This is an initial flow-rate setting and may not be the final optimized-flow-rate.

(4) Oxygen effect: check the response of the detector with various concentrations of oxygen in the sample. Conduct this test with the oven temperature set as required by step III B (2). The initial fuel flow shall be the same as that determined by step III B (3).

(a) Zero the analyzer with hydrocarbon-free air. Introduce nitrogen (N_2) zero-gas. The response to the nitrogen zero-gas must be less than 0.5 percent of full-scale value of the lowest anticipated range.

(b) The following blends of calibration gases shall be used to determine the effect of oxygen (O_2) in the sample.

Calibration-Gas	O_2 concentration	Balance
Propane	21%	N_2
Propane	15%	N_2
Propane	10%	N_2
Propane	5%	N_2
Propane	0%	N_2

The oxygen-concentration blend-tolerance is ± 1% (i.e. 10 ± 1% means 9% to 11%). The analysis of the oxygen-concentration must be within ± 1% of the absolute concentration-value. The calibration-gas concentration should be about 80 ppm C ± 20 ppm C and must be known within ± 1% of the absolute concentration-value.

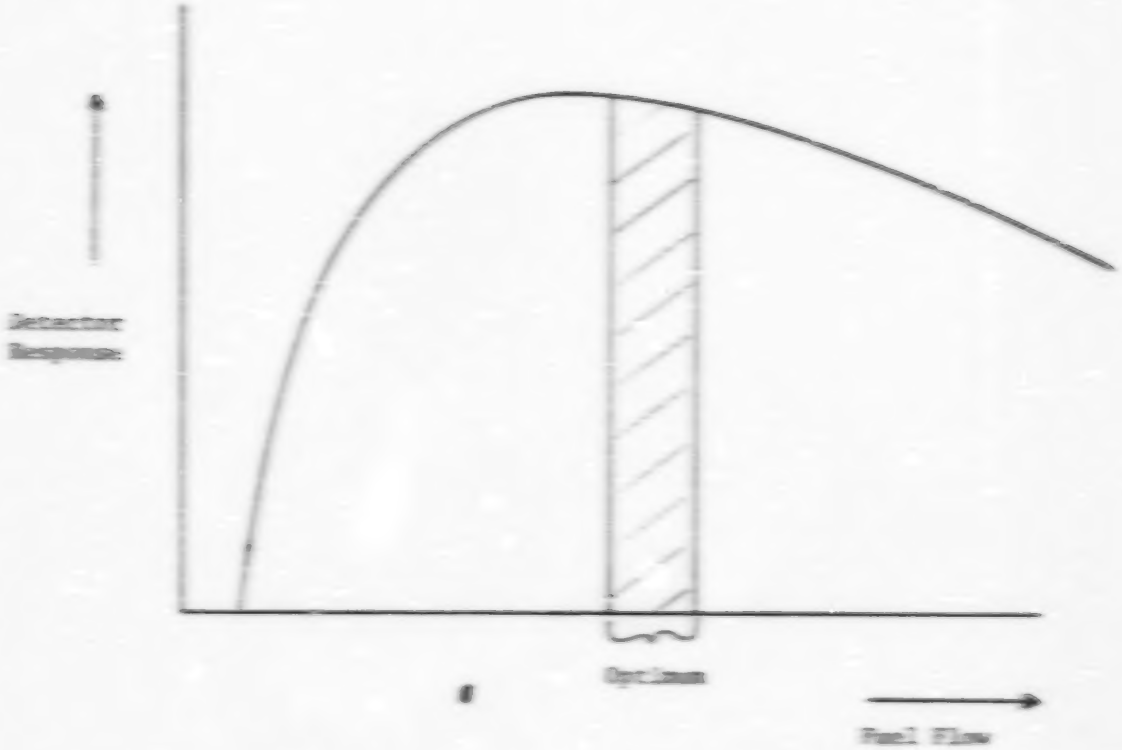

Figure III - 1

(c) Calibrate the analyzer with the calibration mixture containing 21% oxygen.

(d) Introduce the calibration mixtures containing the 15, 10, 5 and 0 percent oxygen to the detector in sequence. Record the response to each of the mixtures.

(e) Recheck the zero response. If it has changed, repeat the test.

(f) Calculate the oxygen interference (% O_{2I}) for the 15, 10, 5, and 0 percent oxygen-mixtures by equation III-1.

(III-1) % O_{2I} = $\frac{Rx - \text{Analyzer Response (ppm C)}}{Rx}$

where

Rx = hydrocarbon concentration of the oxygen-interference cylinders (15%, 10%, 5% and 0%)

(III-2) Analyzer Response =

$$\frac{\text{[hydrocarbon concentration (ppm C) in the 21\% mixture]}}{\text{\% of full-scale analyzer response due to 21\% mixture}} (100) \quad (\text{\% of Full-Scale analyzer response due to Rx})$$

(g) If the oxygen interference for the 15, 10, and 5 percent oxygen mixtures is less than ± 2% and less than ± 2.5% for the zero percent oxygen mixture, then no oxygen-interference correction-factor need be used.

(h) If the oxygen interference is greater than the specifications, incrementally adjust the air flow above and below the manufacturer's specifications, and repeat subparagraphs (c) through (g) of step III C (4).

(i) If the oxygen interference is still greater than the specifications, repair or replace the detector.

(5) Linearity:

(a) With the fuel flow, air flow, and sample flow adjusted to meet the oxygen interference specification, the instrument linearity shall be checked for the ranges covering the range of analysis using propane-in-air with nominal concentrations of 30, 60, and 90 percent of full-scale of each range. The deviation of a best-fit curve from a least-squares best-fit

straight line should not exceed 2 percent of the value at any point. If this specification is met, concentration values may be calculated by use of single calibration factor.

Note, by varying the air, fuel, and sample flow-rates within the boundaries of the oxygen interference specifications, the analyzer may produce a more linear response. If the deviation exceeds 2 percent at any point, concentration values shall be calculated from a calibration curve prepared during this alignment procedure (III C (5)).

(b) With the exception of any possible changes required by subparagraph (6) of III C, the flow-rate, air flow-rate, and sample flow-rate are defined as "optimized" at this point.

(6) Initially, and within every 180 days thereafter, make a comparison of response to the different classes of compounds using (individually) propylene, toluene, n-hexane, and propane, each at 20 to 30 ppm C concentration in air. If the response to propylene, toluene, or n-hexane differs by more than 5 percent from the response to propane, check instrument operating parameters. Reducing sample flow rate generally improves uniformity of response.

IV. Oxides of Nitrogen (NO_x) Analyzer:

A. Analyzer description: The method of measuring total oxides of nitrogen consists of two distinct operations. First the nitrogen dioxide (NO_2) in the sample is converted to an equivalent amount of nitric oxide (NO). Next this amount of (NO) is added to the NO that was already in the sample. This total amount of NO is then measured by the chemiluminescence method.

(1) NO_2 → NO Convertor: There are at least two methods of converting NO_2 to NO. The most frequently used methods employ either a thermal-conversion principle or a combination of thermal-conversion and catalytic-conversion. In order to meet the sample response-times required, it is usually necessary to employ a high flow-rate convertor. The governing criterion for the convertor is that it must have a minimum conversion efficiency of 90% when converting NO_2 → NO.

(2) Chemiluminescence Reaction Chamber: The chemiluminescence method utilizes the principle that nitric oxide (NO) reacts with ozone (O_3) to give nitrogen dioxide (NO_2) and oxygen (O_2). Approximately 10 percent of the NO_2 is electronically excited. The transition of excited NO_2 to the ground state yields a light emission (600-2600 nanometer region at low pressures). The detectable

region of this emission depends on the PM-tube/optical filter being used in the detector. The intensity of this emission is proportional to the mass flow rate of NO into the reactor. The light emission can be measured utilizing a photomultiplier tube and associated electronics.

B. Analyzer specifications: Specifications for the oxides of nitrogen analysis system are:

Response time (pneumatic)--15 percent of full-scale in 1.5 seconds or less.

Response time (electrical)--95 percent of full-scale in 0.5 seconds or less.

Noise--Less than 1 percent of full-scale.

Repeatability--±1 percent of full-scale.

Zero drift--Less than ±1 percent of full-scale in 2 hours.

Span drift--Less than ±1 percent of full-scale in 2 hours.

Linearity--Linear to within ±2 percent of full-scale on all ranges.

C. System optimization:

(1) Follow manufacturer's instructions for instrument start-up and basic operating adjustments.

(2) NO_2 - NO Converter Check: The apparatus described and illustrated in Figure IV-1 is to be used to determine the conversion efficiency of devices that convert NOx to NO. The following procedure is to be used for determining the values to be used in Equation IV-1.

(a) Attach the NO/N_2 supply (150-250 ppm) at C2, the O_2 supply at C1 and the analyzer inlet connection to the efficiency detector at C3. If lower concentrations of NO are used, air may be used in place of O_2 to facilitate better control of the NO_2 generated during step (d).

(b) With the efficiency detector variac off, place the NOx converter in bypass mode and close valve V3. Open valve NV2 until sufficient flow and stable readings are obtained at the analyzer. Zero and span the analyzer output to indicate the value of the NO concentration being used. Record this concentration.

(e) Open valve V1 (on/off flow control solenoid valve for O_2) and adjust valve MV1 (O_2 supply metering valve) to blend enough O_2 to lower the NO concentration (b) about 10 percent. Record this concentration.

(d) Turn on the ozonator and increase its supply voltage until the NO concentration of (c) is reduced to about 20 percent of (b). NO_2 is now being formed from the NO + O_2 reaction. There must always be at least 10 percent unreacted NO at this point. Record this concentration.

(e) When a stable reading has been obtained from (d), place the NOx converter in the convert mode. The analyser will now indicate the total NOx concentration. Record this concentration.

(f) Turn off the ozonator and allow the analyser reading to stabilize. The mixture NO + O_2 is still passing through the converter. This reading is the total NOx concentration of the dilute NO span gas used at step (c). Record this concentration.

(g) Close valve V1. The NO concentration should be equal to or greater than the reading of (b) indicating whether the NO contains any NO_2. Calculate the efficiency of the NOx converter by substituting the concentrations obtained during the test into Equation (IV-1).

$$\text{(IV-1)}\quad \% \text{ Eff.} = \left[1 + \frac{[(e) - (f)]}{[(c) - (d)]}\right] \times 100\%$$

The efficiency of the converter should be greater than 90 percent. Adjusting the converter temperature may be needed to maximize the efficiency. Although steps (b) and (g) are not used in the calculations, their values should be recorded to complete the data set for the test sequence. This procedure does not depend on the amount of NO_2 in the span gas nor the equivalence of flows in the by-pass and converter modes. However, to be consistent with good operating practice, flows should be nominally the same, and the NO_2 concentration should be less than 5% of the NOx span concentration. Efficiency checks shall be made weekly.

(h) If the converter does not meet the conversion-efficiency specifications, repair or replace the unit.

(3) Carbon Dioxide (CO_2) and carbon monoxide interference check:

(a) Calibrate the NOx analyzer on the lowest anticipated range that may be used during testing.

(b) Introduce (separately) blends of CO_2/NOx and CO/NOx (diluent N_2) to the analysis system. The CO_2 and CO concentrations should be approximately equal to the highest concentration that may be measured during testing. The NOx concentration should be similar to the concentration used in step a). Record the response.

(c) Recheck calibration. If it has shifted, recalibrate and rerun the interference test.

(d) The difference between the NOx response with the interference gases and the calculated NOx response must not be greater than ± 2 percent. The calculated response is based on the calibration curve (Step (c)) and the interference-bottle NOx concentration.

(e) The interference from CO_2 and CO in this checking procedure must be less than 2 percent.

(4) Linearity:

(a) With the operating parameters adjusted to meet the convertor efficiency check and the interference checks, the instrument linearity shall be checked for the ranges of analysis using NO in N_2 at nominal concentrations of 30, 60, and 90 percent of full-scale of each range. The deviation of a best-fit curve from a least-squares best-fit straight line should not exceed 2 percent of the value at any point. If this specification is met, concentration values may be calculated by use of a single calibration factor. If the deviation exceeds 2 percent at any point, concentration values shall be calculated from a calibration curve prepared during this alignment procedure (IV C (4)).

(b) The operating parameters are defined as "optimized" at this point.

V. Humidity Calculations:

A. The specific humidity (H) is defined by equation (V-1).

$$(V\text{-}1)\quad H = \frac{K\,Pv}{BARO - Pv}$$

where

BARO = barometric pressure (Pa)

Pv = partial pressure of water vapor (Pa)

$$K = \frac{\frac{(18.01534 \text{ lb. of } H_2O)}{\text{lb. Mole}}}{\frac{(28.967 \text{ lb. of Dry Air})}{\text{lb. Mole}}} = \frac{\frac{(18.01534 \text{ gm of } H_2O)}{\text{gm Mole}}}{\frac{(28.967 \text{ gm of Dry Air})}{\text{gm Mole}}} = .6219$$

$$\text{units of } H = \frac{\text{lb. of } H_2O}{\text{lb. of Dry Air}} = \frac{\text{gm of } H_2O}{\text{gm of Dry Air}}$$

6. The partial pressure of water vapor may be determined in two manners:

(1) A dew point device may be used. In that case:

$P_v = P_{DP}$ = saturation vapor pressure of water at the Dew-Point temperature. (Pa)

(2) A wet-bulb, dry-bulb method may be used. In that case "Ferrels equation" (eq. (V-2)) is used.

$$(V\text{-}2)\quad P_v = P_{WB} - (3.67)(10)^{-4}\,(BARO)(t_{db} - t_{wb})\left[t_{wb} + \frac{1533}{1571}\right]$$

P_{WB} and (BARO) must have the same units

where

t_{db} = Dry bulb temperature (°F)
t_{wb} = Wet bulb temperature (°F)

6. The saturated vapor pressure of water at the wet-bulb temperature (P_{WB}) is defined by equation (V-3) (Ref. Wexler and Greenspan, equation (23), National Bureau of Standards).

$$(V\text{-}3)\quad P_{WB} = (e)\left[B \ln T_{WB} + \sum_{i=0}^{9} F_i\, T_{WB}^{\,i-2}\right]$$

where

P_{WB} = is in Pascals (Pa)
T_{WB} = Wet-bulb temperature (°K)

$B = -12.150799$
$F_0 = -8.49922(10)^{3}$
$F_1 = +7.4231865(10)^{3}$
$F_2 = 96.1635147$
$F_3 = 2.4917646(10)^{-2}$
$F_4 = -1.3160119(10)^{-5}$
$F_5 = -1.1460454(10)^{-8}$
$F_6 = 2.1701289(10)^{-11}$
$F_7 = -3.610258(10)^{-15}$
$F_8 = 3.8504519(10)^{-18}$
$F_9 = -1.4317(10)^{-21}$

D. The saturate vapor pressure of water at the dry-bulb temperature (P_{DB}) is found (if required) by using dry-bulb absolute-temperature (°K) in equation (V-3).

E. The percent of relative humidity (RH) (if required) is defined by equation (V-4).

$$(V\text{-}4)\quad RH = \frac{P_W}{P_{DB}}\ (100)$$

(6) The water-vapor volume concentration of the engine intake air (Y) is defined by equation (V-5):

$$(V\text{-}5)\quad Y = \frac{(H)\ (M_{air})}{(M_{H_2O})} = \frac{P_V}{BARO - P_V}$$

where

M_{air} = Molecular weight of air = 28.967

M_{H_2O} = Molecular weight of water = 18.01534

VI. Airflow Measurement: There are many different methods of measuring airflow to Diesel and gasoline engines. The method used should have a turn-down ratio large enough to accurately measure the airflow over the engine operating range during the test. Preferred measurement techniques include measurement by a laminar flow device or a vortex shedding device. Other techniques may be used; however, the overall measurement accuracy should be ±1 percent of full-scale value of the measurement device.

(1) Engine System: When measuring inlet air, various engines systems may have additions or subtractions of small quantities of air downstream of the airflow measuring device. An example of air addition would be an air injection system (i.e. air pump). An example of air subtraction would be compressor bleed-air that

is used to operate an intercooler fan on a turbocharged engine. This bleed-air is normally vented to the atmosphere and does not pass through the engine. In determining the (f/a) ratio for the required calculations, use the following conventions:

(a) Wet to Dry conversion factor (K_w): When calculating the (f/a) ratio to be used in determining K_w, use only the airflow entering the combustion chamber. This may require substraction of bleed-air, etc. from the measured airflow.

(b) Fuel/Air ratio comparison: When comparing measured (f/a) ratio to an emissions calculated (f/a) ratio the, measured airflow (in terms of mass) is the total mass of air entering the exhaust pipe. This may include additions of air mass to the exhaust pipe by an air injection system.

(2) Corrections to the measured air mass-flow-rate: When an engine system incorporates devices that add or substract air mass as determined by VI (1), determine the air mass from these devices by one of the following methods:

(a) Measure the air mass-flow from the device during each operating mode.

(b) Determine that the air mass-flow for each mode from the device is typical for many system applications. Then the device flow-rate for each mode may be generally applied.

(c) Under certain circumstances, such as turbomachinery, theoretical calculations that predict the device mass flow-rate during each mode may be used.

(3) Gasoline fueled engine systems: When measuring air flow-rate of a gasoline engine, special care must be taken in the areas of flow distribution, velocity profiles, and pressure drop to the engine system:

(a) Flow distribution: The air-cleaner is considered part of the engine system. Flow distribution should be considered as flow distribution to the air cleaner. A plenum chamber of sufficient volume is recommended to insure uniform distribution to the engine.

(b) Velocity profile: The velocity profile is considered the velocity profile to the air cleaner. The shape of the plenum chamber and the entrance to the plenum chamber in-

fluence the velocity distribution. The desired condition is a uniform velocity - profile with a velocity between 3.3 to 13.2 metres per second (10 to 40 feet per second delivering air to the air cleaner.

(c) Pressure drop: During the measurement process of air flow, the velocity at the point of measurement is usually quite high, i.e. as high as 51 metres/sec (200 ft/sec). In order to slow this velocity down to the desired velocity range in the plenum chamber without incurring additional pressure-losses, it is recommended that a diffusser be used between the air-flow measurement device and the plenum chamber. In any case, the pressure drop (from atmospheric pressure) at the inlet to the air cleaner should not be more than 1.74 kPa (7.0 in H_2O).

(d) Vents: Devices like PCV valves that vent to the air cleaner, should continue to be vented to the air cleaner. Devices that vent to the atmosphere as some carburetor float vents, governors, etc. should vent to the plenum chamber.

(e) Hot air: Engine inlet air temperatures: Due to the preconditioning schedule, ambient soak, and subsequent warm-up idle, the first test-sequence should not be considered a cold test-sequence. Therefore, considering current under-hood-temperatures on a 20°C (68°F) to 30°C (86°F) day, devices that provide hot air to the carburetor are defined as non-functional during the test sequence. Use the following convention in determining the inlet air temperature to the engine:

(A) Ducted Ambient-Air: On engines that use ducted ambient-air to the carburetor, the hot-air device should be non-functional during the test sequence. The engine should induct ambient air at 20°C (68°F) to 30°C (86°F).

(B) Under-Hood Air: On engines that induct air under the hood, the hot air device (if used) will be non-functional during the test sequence. The engine should induct air at a typical under hood temperature that would occur on a 20°C (68°F) to 30°C (86°F) day. The manufacturer should specify and substantiate the under hood intake air temperature.